

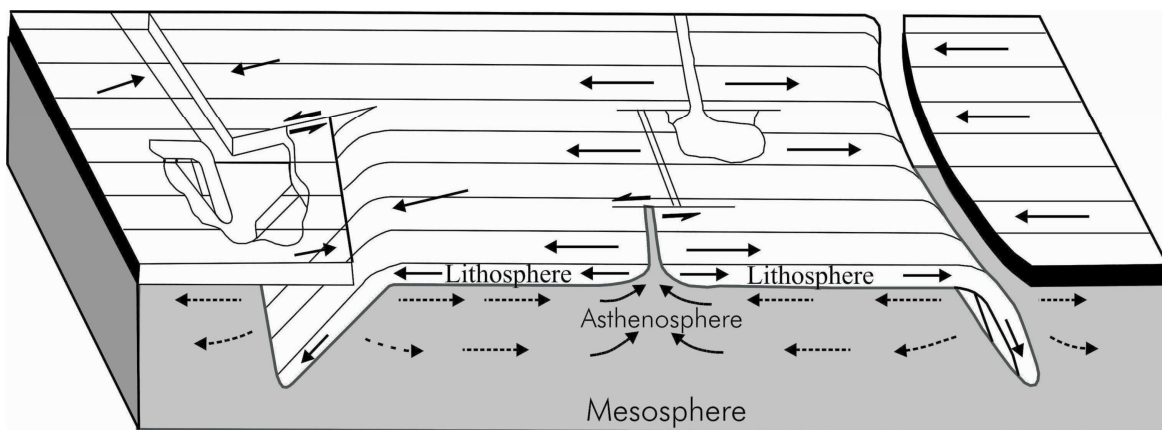
Class Notes
on
Mid Oceanic Ridge, Triple Junctions & 90° E Ridge

Part of subject GPM 203 Geodynamics

by

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PLATE BOUNDARIES AND PROCESSES



Lithospheric plate motions in three dimensions shows plate generation along the mid-ocean ridges; relative movement of adjoining blocks away from the ridges and the subduction of the cold sinking slabs to great depths beneath the trenches as shown in the figure above. One arc-to-arc transform fault appears at left between oppositely facing zones of convergence (island arcs). (after Isacks, Oliver and Sykes, 1968).

Plate Tectonics distinguishes three types of boundaries:

- mid-ocean ridges where the plates move away from each other (divergent boundaries) and new lithosphere is being created through the process known as sea-floor spreading (ex: the mid-Atlantic Ridge);
- subduction zones where the plates move towards each other (convergent boundaries) and lithosphere is being recycled into the mantle (ex: subduction of the Nazca and South American plates in Peru); and
- transform faults where the plates pass by each other (strike-slip boundaries; ex: The San Andreas Fault).

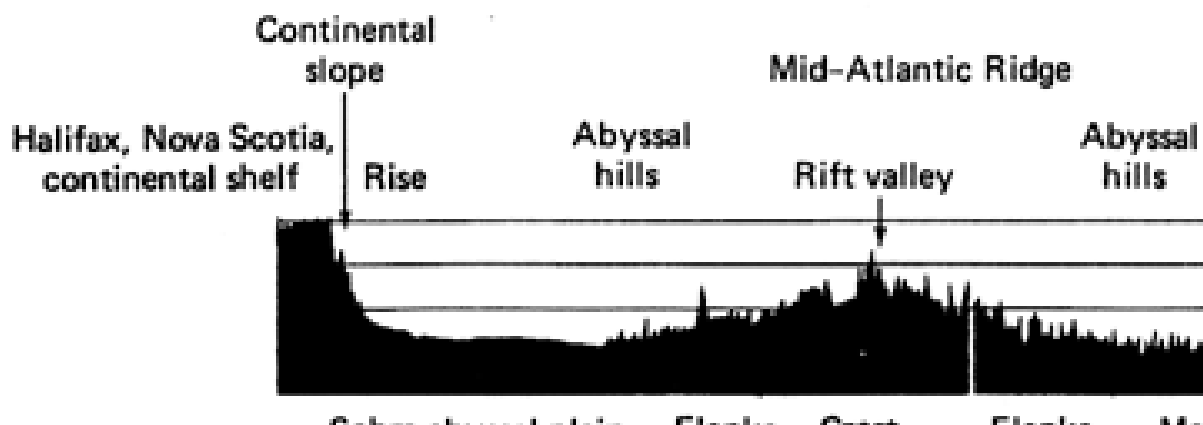
MID-OCEANIC RIDGES (MOR)

The Atlantic, Indian and South Pacific oceans are traversed by a continuous, broad, fractured swell known as the mid-oceanic ridge. There is a crest zone of extremely rugged relief and a broader, rugged flank on either side. The mid-oceanic ridges today are 60,000 km (about 40,000 mi) long, forming the largest continuous mountain chain on earth. This ridge goes all the way around the globe. Earthquakes, faults, underwater volcanic eruptions, and vents or openings, along the mountain crests produce rugged seafloor features, or topography. The Mid-Atlantic Ridge is currently spreading at a rate of 2.5 cm per year (1 in per year).

The earth's solid surface is about 40 percent continental crust. Continental crust is much older, thicker and less dense than oceanic crust. Generally, the continental crust between plates that are moving apart is very thin, about 20 km (about 10 mi) thick. In other places, such as mountain ranges, the crust ranges from 30 to 70 km (from 20 to 40 mi) thick. Near the surface, it is composed of rocks that are felsic (made up of minerals including feldspar and silica). Deeper in the continental crust, the composition is mafic (made of magnesium, iron, and other minerals).

Oceanic crust makes up the other 60 percent of the earth's solid surface. Oceanic crust, in general, is thin and dense. It is constantly being produced at the *mid-oceanic ridges*-undersea volcanic mountain chains formed at plate boundaries. This production of crust does not increase the physical size of the earth, so the material produced at mid-oceanic ridges must be recycled, or consumed, somewhere else. It is believed that the older oceanic crust is recycled back into the earth in subduction zones, where one plate sinks underneath another and the crust of the sinking plate melts back down into the earth. Oceanic crust is continually recycled so that its age is generally not greater than 200 million years. Oceanic crust averages between 5 and 10 km (between 3 and 6 mi) thick. It is composed of a top layer of sediment, a middle layer of rock called basalt, and a bottom layer of rock called gabbro. Both basalt and gabbro are dark-colored igneous or volcanic rocks.

The elevation of ocean ridges decreases as a function of distance from the ridge crest.

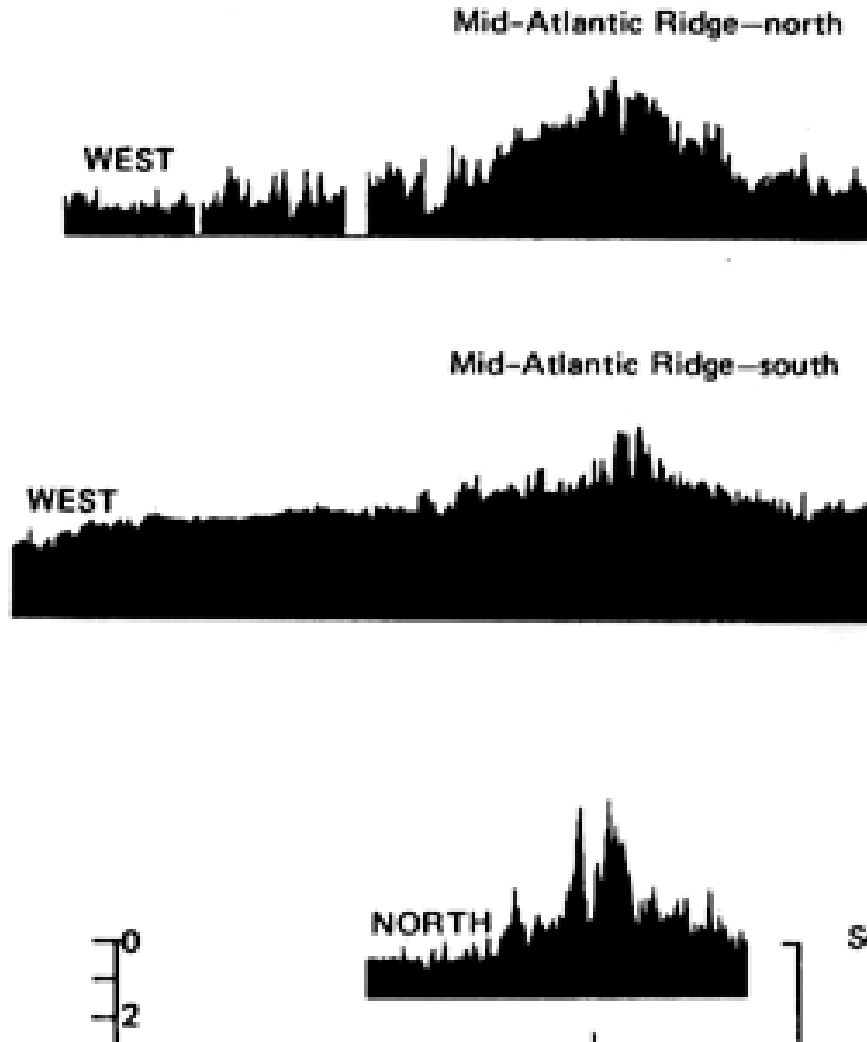


Principal morphologic features along profile across the North Atlantic between North America and Africa (from Holcombe, 1977).

As the lithosphere moves away from the ridge axis, it cools and its density increases; therefore it "sinks" more deeply into the fluid-like asthenosphere. This vertical adjustment of the lithosphere is called *isostasy*.

The rift valley lies along the axis of the ridge and coincides with the belt of mid oceanic earthquakes of epicenters. The rugged mountains parallel the rift valley on either side. Flank provinces descend to the ocean basin floor on each side of the crest. All major features of the mid oceanic ridge systems are roughly parallel to the axis of the ridge median rift and to the major trend of the continental margins.

Mid-ocean ridges are the site of a large fraction of the Earth's volcanism. This volcanism is caused by pressure-release melting of the asthenosphere. Low-melting point, basaltic component melts are generated to form the oceanic crust. The residual (which will form the underlying mantle lithosphere) is *peridotite*.



Selected profiles across mid-ocean ridges. Profiles in Atlantic and Indian oceans exhibit a well-defined rift valley set within very rugged relief. The South Pacific profile of the East Pacific rise lacks a rift valley. Baseline is 6500 m for all profiles (from Heezen and Ewing, 1963).

The rifted mid-oceanic ridge impinges on the continents in several places. It traverses the Gulf of Aden. *Since they form parts of the continuous feature, we can infer that both are the result of similar tectonic processes.*

The mid Atlantic ridge extends through Iceland and the central graben of Iceland with extension of the mid oceanic rift. All quaternary volcanism in Iceland is localized in the central graben.

In the east Pacific, the Easter Island Ridge runs north-east towards the Gulf of California. The epicenter belt, which is continuous along the axis of the Easter Island ridge extends into the Gulf of California and appears to connect with the three seismicity belts of western United States. The eastern branch follows a line of general trench, including the rocky mountain trench. The middle part extends up to Inyo valley on the east flank of the Sierra Nevada, and the western flank follows the San Andreas Fault of California to a point north of Cape Mendocino.

Seismic refraction measurements in the north Atlantic and across the Eastern Pacific reveal that the structure of the mid-oceanic ridge strongly contrasts with the typical ocean basins. It shows the velocity from 7.2 to 7.4 km/sec. Normal velocity of 8.2 km/sec have never been found in the crest province of the ridge.

Strong positive magnetic anomalies were found to be characteristic of most crossings of the rift valley in the north and south Atlantic. However, only a few of the profiles across the rift valley of the Indian ocean revealed such anomaly. They may be due to high magnetic susceptibility lies beneath the rift valley.

Free air gravity anomalies were much lower over the rift valley than over adjacent rift mountains, but when the effect of topography are considered, the values over the rift are not found to be anomalous. *Thus neither gravity nor magnetic offers a definitive evidence of a unique crustal structure beneath the rift valley.*

DEVELOPMENT AND PROCESS OF GROWTH OF TECTONIC PLATES or TRIPPLE JUNCTION OR TRIPLE POINT JUNCTION

The mid oceanic ridges are broken by transform faults or transcurrent faults. Different sectors move laterally along the fault with varying drift rates. On the earth's surface, there are several points where three plates meet are called triple junction. The East African Rift Zone is a good example of a triple plate junction. The African plate is splitting into two plates and moving away from the Arabian plate as the Red Sea meets the Gulf of Aden. Mendocino Triple Junction, which occurs at the intersection of two transform faults (the San Andreas and Mendocino faults) and the plate boundary between the Pacific and Gorda plates, is another example of tripple junction. The analyses of plate evolution i.e. development of growth/ consumption of plates can be explained through the stability/ instability of triple junction. The stability of triple junction has some bearing on the interpretation of the magnetic anomalies in the oceanic areas across the ridges. In certain regions, some magnetic anomalies have been destroyed by consumption of plates. Such cases can be explained by unstable nature of triple junction. Seven types of triple junctions have been identified such as: Ridge-Ridge-Ridge (RRR), trench -trench -trench (TTT), Trench-Trench-Fault (TTF), Fault- Fault-Ridge (FFR), Ridge-Trench-Fault (RTF), and Ridge-Ridge-Trench (RRT). The above triple junctions have been found in oceanic areas. The nature of triple junctions is shown in Table 1. Fig. 1 shows the triple junction formed by a ridge, trench and transform fault and their relative velocities.

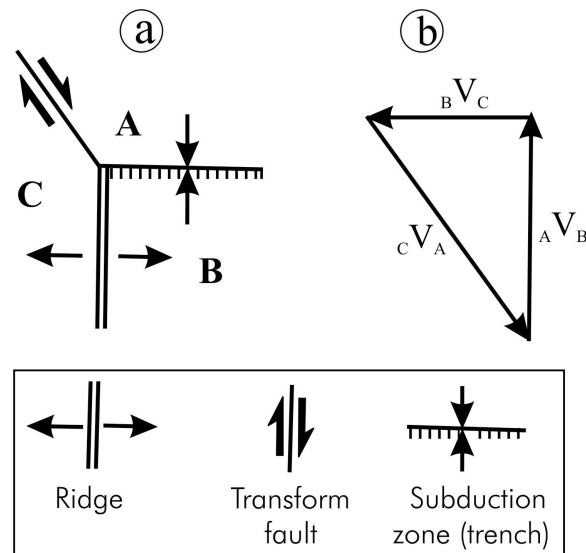


Fig. 1: (a) Triple junction formed by a ridge, trench and transform fault; (b) vector diagram of the relative velocities at the three boundaries (after McKenzie and Parker, 1967)

A triple junction between three trenches can thus be stable in certain conditions. If the above conditions are not met, the triple junction would be unstable i.e. it may change its position affecting development and process of growth of different plates. *The junction of three transform faults is always unstable whereas the junction of three ridges spreading perpendicular to their axis is always stable. Junction with two boundaries on a straight line fixed with respect to the plate which they bound, also always stable.*

The following facts are important to understand the triple junctions (Fig. 2):

- 1) *Accreting plate margins (mid-ocean ridge crest) is defined as lines of relative motions along which surface is produced symmetrically. The actual relative direction of motion need not be perpendicular to this line.*
- 2) *Consuming plate margins (trenches or young mountain belts called “arcs” by Wilson) are defined as lines of relative motion along which surface (generated at MOR) is destroyed asymmetrically. Here the surface is destroyed on one side of the line (one of the plate is underthrust by the other). The direction of relative movement need not be, and in general is not, perpendicular to this line.*
- 3) *Transform faults are lines of relative motions along which surface is conserved. The relative movement along the line is pure strike-slip and, consequently, transform faults are the only lines which give us the direction of relative motion between plates.*

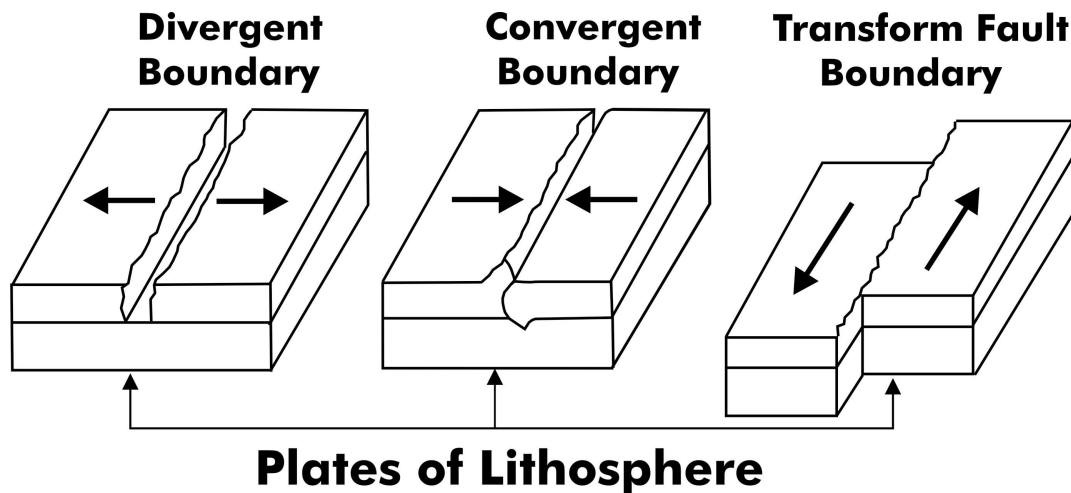


Fig. 2: Types of plate boundaries (modified from NSTA/FEMA, 1988)

Stability of Triple Junction

The stability of the boundaries between plates is dependent upon their relative velocity vectors. If a boundary is unstable it will exist only instantaneously and will immediately devolve into a stable configuration.

An unstable boundary between two plates where X is underthrusting plate Y at **bc** in a northeasterly direction and plate Y is underthrusting plate X at **ab** in a southwesterly direction (Fig. 3a). The boundary is unstable because a trench can only consume in one direction, so to accommodate these movements a dextral transform fault develops at **b** (Fig. 3b). This sequence of events occurred in the development of the Alpine Fault of New Zealand (Fig. 3c), which is a dextral transform fault linking the Tonga-Kermadec Trench, beneath which Pacific lithosphere is underthrusting in a southwesterly direction, to a trench to the south of New Zealand where the Tasman Sea is being consumed in a northwesterly direction.

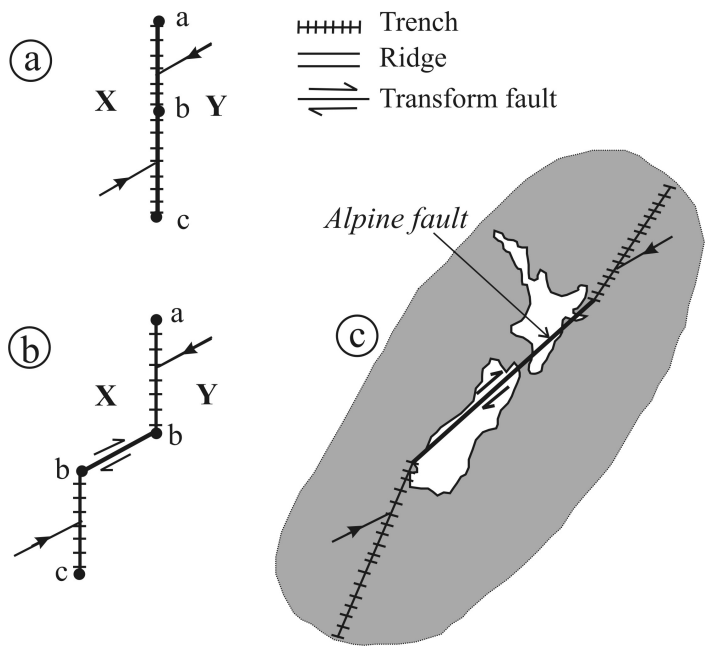


Fig. 3: Evolution of a trench (a & b).
Alpine Fault of New Zealand (c)
(Kearey and Vine, 2006)

The direction of motion of the plate of FRT and RRR types of triple junction is shown in Figs. 1 & 4 respectively. ${}_A V_B$ denote the velocity of plate B relative to plate A, ${}_B V_C$ the velocity of plate C relative to plate B and ${}_C V_A$ the velocity of plate A relative to plate C. The quantities are vectors and their directions are as important as their magnitudes. They can be represented by vector diagram through straight line as shown in Fig. under Table 1. The vector diagram of the inter-plate velocities is related by:

$${}_A V_B + {}_B V_C + {}_C V_A = \mathbf{0} \dots\dots\dots(1)$$

For a junction to preserve its geometry, the orientation of the three plate boundaries must full fill the condition laid under eq. (1). If they do so, the junction is stable and can maintain its shape otherwise the junction is unstable.

When several plates are dealt with, the rigidity of the plate implies that when taking a circuit which begins and ends in the same plate, the sum of the relative velocity vector be zero as given above. The geometry and velocity triangle for a triple junction formed by three ridges are shown in Fig. 4.

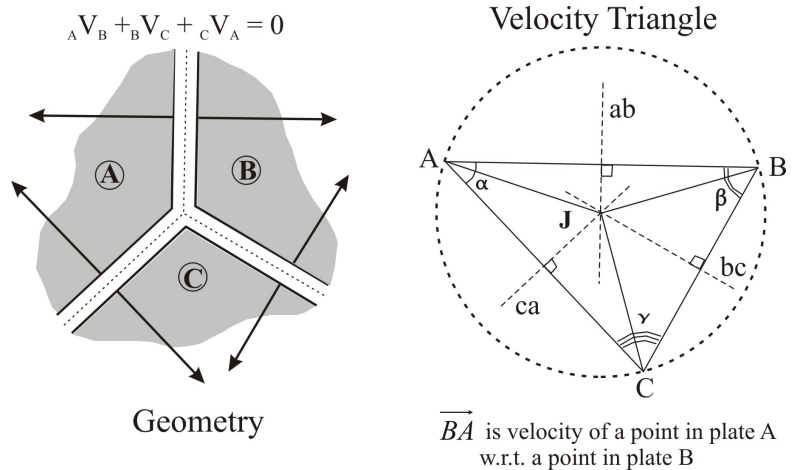


Fig. 4: Triple point junction of three ridges and corresponding velocity triangle. In the velocity plane, the velocity of a point of plate A with respect to a point of plate B is represented by the vector BA. Thus point A in the velocity triangle corresponds to the velocity of the infinitesimal portion of point plate A near the triple junction (redrawn from McKenzie and Morgan, 1969).

Table 1: The geometry and stability of all possible triple junctions.

Geometry and stability of triple junctions				
Type	Geometry	Velocity triangle	Stability	Example
RRR			All orientations stable	East Pacific Rise and Galapagos Rift zone Great Magnetic Bright
TTT (a)			Stable if ab, ac form a straight line or if bc is parallel to the slip vector CA	Central Japan
TTT (b)			Stable if the complicated general condition for ab, bc and ac to meet at a point is satisfied	
FFF			Unstable	
RRT			ab must go through circumcentre of ABC	
RRF			Unstable, evolves to FFR	
TTR (a)			Stable if ab goes through C, or if ac, bc form a straight line	
TTR (b)			Stable if complicated general conditions are satisfied	

Table 1 (continued)

Geometry and stability of triple junctions

Type	Geometry	Velocity triangle	Stability	Example
TTR (c)			Stable if the angles between ab and ac, bc respectively, are equal, or if ac, bc form a straight line	
TTF (a)			Stable if ac, bc form a straight line, or if C lies on ab	Intersection of the Peru-Chile Trench and the Chile Ridge
TTF (b)			Stable if bc, ab form a straight line, or if ac goes through B	
TTF (c)			Stable if ab, ac form a straight line, or if ab bc do so.	
FFR			Stable if C lies on ab, or if ac, bc form a straight line	Owen Fracture Zone and the Carlsberg Ridge, West Chile Ridge and the East Pacific Rise
FFT			Stable if ab, bc form a straight line, or if ac, bc do so	San Andreas Fault and Mendocino Fracture Zone
RTF (a)			Stable if ab goes through C, or if ac, bc form a straight line	Mouth of the Gulf of California
RTF (b)			Stable if ac, ab cross on bc	

90° E RIDGE

Indian plate started drifting towards north some 75 my ago and continued up to 55 my. Thus rapid motion blocked thereafter. During this time spreading started along southeast branch of Indian Ocean ridge system and it resulted in separation of Australia from Antarctica about 45 my ago. A ridge along 90° E was developed between India and Australia which is called 90° East Ridge. It extends from 30° S to 20° N. Along this ridge, basaltic material came out from the upper mantle separating India and Australia. Presently this ridge is not very active; however a few earthquakes have been reported to occur there. Certain volcanic eruptions have also taken place. Owing to development of 90° E ridge and Chagos ridge, the Indian plate is moving towards north with the annual drift rate of 50 mm whereas Australian plate is drifting with a slower rate. At present, the 90° E ridge and Owen fractured zone are behaving like a weak zone along which Indian plate is drifting towards north as shown in the figure 5 below.

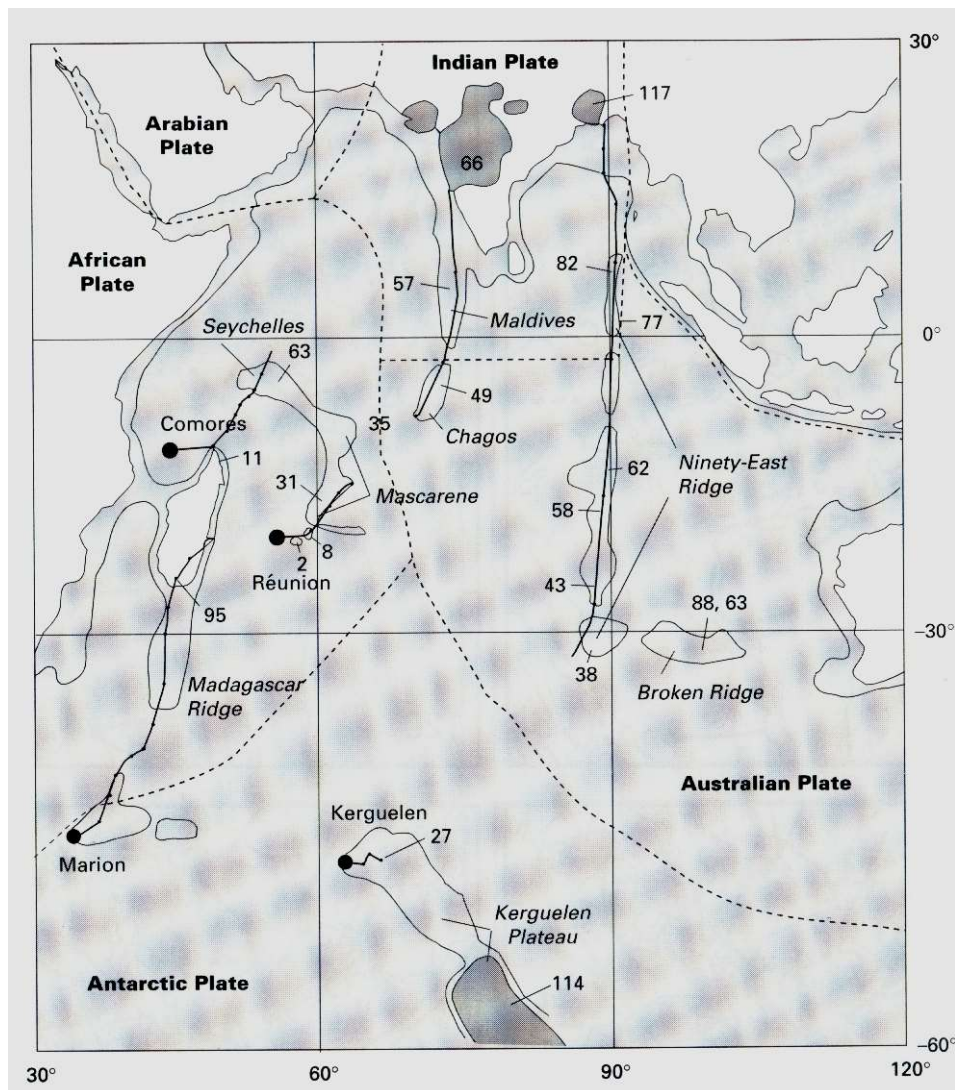


Fig. 5: Location of 90° E and Chagos ridges along with hotspot tracks in the Indian Ocean. Solid circles show present locations of hotspots. Numbers refer to radiometrically dated locations in million of years. Dark stipple marks flood basalt provinces (Kearey and Vine 2006).